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TESTS OF TUNGSTEN LAMPS

BY

T. H. AMRINE

AND

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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ENGINEERING EXPERIMENT STATION

BULLETIN No. 33

MARCH 1909

TESTS OF TUNGSTEN LAMPS

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I. INTRODUCTION

When the tungsten incandescent lamp was put on the market, about a year and a half ago, its high efficiency and excellent quality of light were in a large measure offset by the extreme fragility of its filament, its uncertain life and its high price. For instance, in October, 1907, when German tungsten lamps were just being introduced into this country, the Engineering Experiment Station bought a dozen of the 40-watt size (the smallest obtainable at that time) for testing purposes, at a cost of \$1.50 each. They came by express, packed with as much care and skill as was thought necessary, but when the lamps were received only five of the twelve had unbroken filaments, and these five had an average life of 50 or 75 hours only. This experience was a typical one with tungsten lamps at that time.

Since then many companies have entered the field of tungsten lamp manufacture, and they have all striven to overcome the faults common to those early lamps. In their attempts to make a lamp that would better withstand shipment and handling, that would not blacken and burn out early in its life and that could be burned in other than the vertical pendant position necessary with the first lamps, the manufacturers have developed several types of tungsten lamps. These differ considerably in two respects: (1) the method of manufacture; and (2) the scheme of mounting the filaments.

This bulletin describes a study of three prominent types of tungsten lamps, differing considerably in the above respects. This study was made with the idea of bringing out, as far as possible, the good as well as the poor points in the construction and manufacture of each type. There are included the results of tests showing what may be expected of the present day low wattage tungsten lamps in the way of life, maintenance of candle power and efficiency under different operating conditions.

II. DESCRIPTION OF LAMPS

Of the lamps chosen for the tests, one type was of American and two were of German manufacture. They will be designated as the *P*, *D* and *C* lamps, respectively. They represented three of the principal processes used in the manufacture, and three common schemes of mounting tungsten lamp filaments at the time the tests were started. All lamps tested were chosen from a lot of 100 of each type of lamp.

Rating.—All three lamps were rated at 25 watts at 110 volts and advertised to give an efficiency of 1.25 watts per candle-power. Fig. 1, 2 and 3 show the candle-power and watt per candle values for the individual lamps when new, and the average curve drawn through these points for the 100 lamps of each kind. It will be seen from the curves that the average watt per candle efficiency of the *C* lamps is somewhat poorer than the others. This can perhaps be explained by the fact that its filament is supported by three times as many spires as the other two, and hence more of

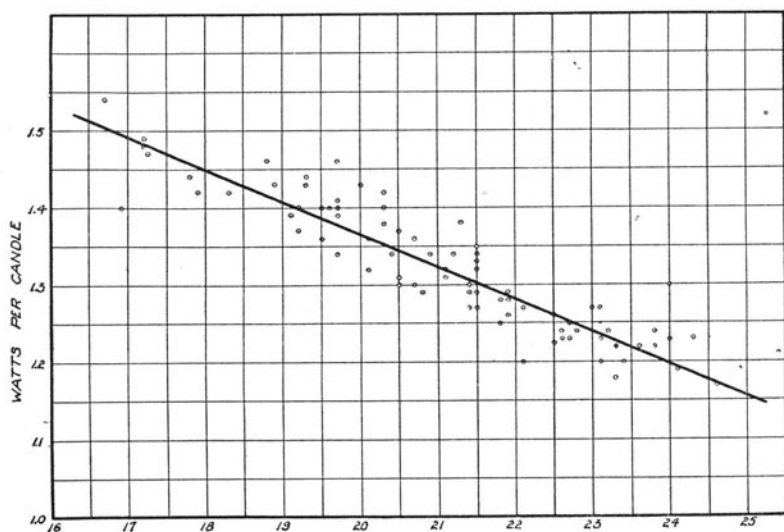


DIAGRAM SHOWING RATINGS OF 100 C LAMPS.

FIG. 1

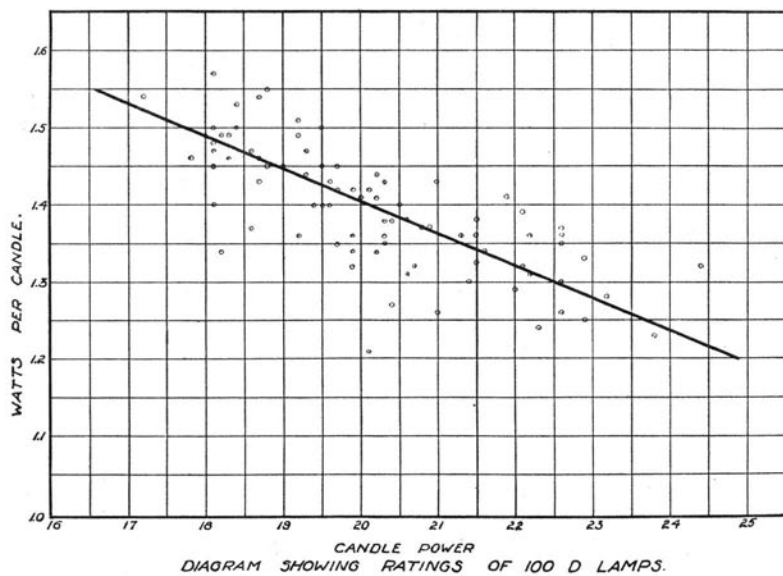


FIG. 2

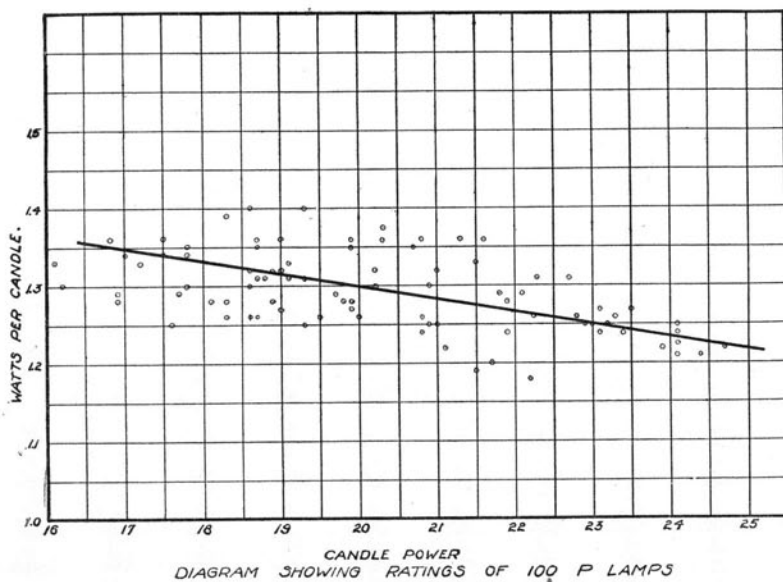


FIG. 3

the filament is kept cooled below incandescence. In the *D* and *P* lamps, each one of the tip end spires cools approximately $1/8$ inch of filament, so that it produces little or no light, while the spires at the base end each cool approximately $1/16$ inch. This makes about one inch of filament in each lamp that acts merely as a resistance. In the *U* lamp there are 16 spires, each cooling a short length, so that there are about 2 1-2 inches of ineffective filament so far as light production is concerned. This would account for the difference in efficiency between this lamp and the other two, since the main part of the filaments is operated at approximately the same temperature.

Filaments.—The filaments of the American lamp (*P*) were manufactured by the paste or Auer process. In this method, which is similar to the one used in making ordinary carbon filaments, finely powdered tungsten is mixed with a suitable binder, such as sugar or some other organic substance, and the resulting paste is squirted through a diamond die under great pressure. The moist filament so formed is then heated in an atmosphere of steam and hydrogen to remove the carbon of the binding material. This leaves a filament of almost pure tungsten. The filament, as mounted in the lamp, consists of four hairpin loops connected in series and mounted upon supporting spires. Connections between the loops are made at the base end of the stem by fusing together the filaments and the spires. The filaments are hung loosely on the spires so as to allow for the contraction that takes place after they have been burned for a time.

The filament of the first German lamp (*D*) is made by the deposition process. In this method a fine filament of carbon is heated in an atmosphere of some compound of tungsten, for instance, oxychloride of tungsten. This causes the metal to be deposited in a shell upon the carbon core. By the application of heat the tungsten and carbon are made to unite chemically to form tungsten carbide, which is then reduced and the carbon removed by a method similar to that employed in the paste process. The

filament in this lamp also consists of four loops, but the supporting spires at the tip end of the stem are very thin and flexible springs, and the filament is kept under a slight tension by their action. The flexibility of these spires also permits contraction of the filaments to take place. The entire glass stem which carries the filaments is mounted between two coil springs, as shown in Fig. 4. The object of these springs is to absorb the jar and vibration to which the lamp may be subjected and so prevent breaking the filament. Connections between the filament and spires at the base end of the stem are made by means of pasted joints.

The second German lamp (*C*) is made by the colloid process. In this method colloidal tungsten is formed either by maintaining an arc between tungsten electrodes under some liquid, it may be water, or by reducing tungstic trioxide with potassium cyanide. This plastic colloidal mass is brought to the proper consistency, and is then squirted through a die to form a filament, as in the paste process. The filament so obtained is dried and is gradually brought to a white heat in a nonoxidizing atmosphere, and is thereby converted into the crystalline state. The filament in this lamp, too, consists of four loops, each of which is mounted in a peculiar spiral shape and hung loosely enough to permit of contraction. The joints between the filaments and the base spires are fused as in the *P* lamp.

TABLE 1
DIMENSIONS OF FILAMENTS

Lamp	Total Length inches	Diameter inches	Total Area of Surface square inches
<i>C</i>	19.87	.00138	.0859
<i>D</i>	15.92	.00202	.1009
<i>P</i>	19.27	.00163	.0987

The shapes of the bulbs and their comparative sizes are shown in Fig 4. The bulb of the *P* lamp is identical with that on the ordinary 16 candle-power carbon lamps in use in this country.

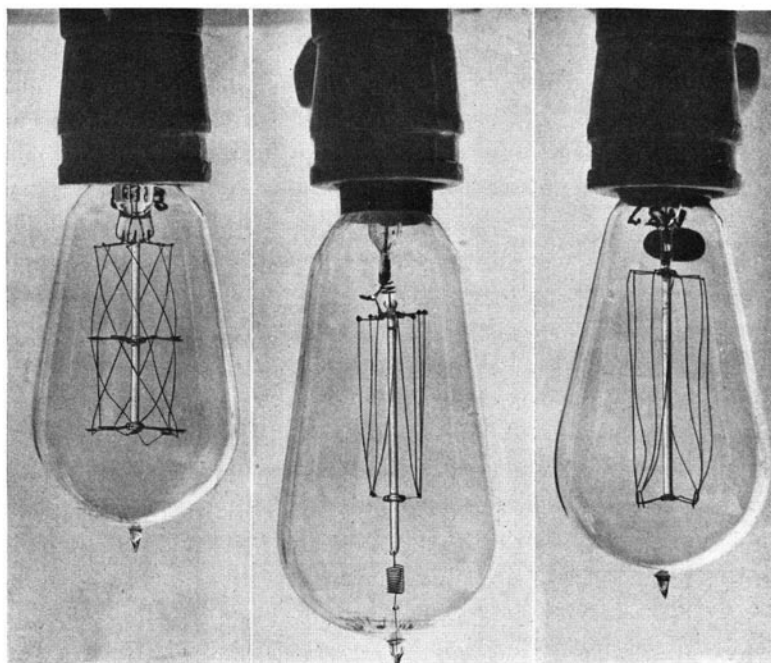
*C**D**P*

FIG. 4

III. ELECTRICAL CHARACTERISTICS¹

All three filaments, being of metal, have of course a positive temperature coefficient. Fig. 5 shows the temperature resistance curves for one lamp, selected at random from each of the three lots of lamps received. Fig. 6 is a curve between current and resistance that is typical of all three lamps.

As is the case with all lamps having filaments with a large positive temperature coefficient, the current, when first turned on, has a value several times greater than the normal operating value. Fig. 7 is a curve taken by means of an oscillograph, showing this change of current from the instant of starting. The very low re-

¹ In some of the curve sheets that follow, curves for only one kind of lamp are given. In these cases the results for all lamps are practically the same.

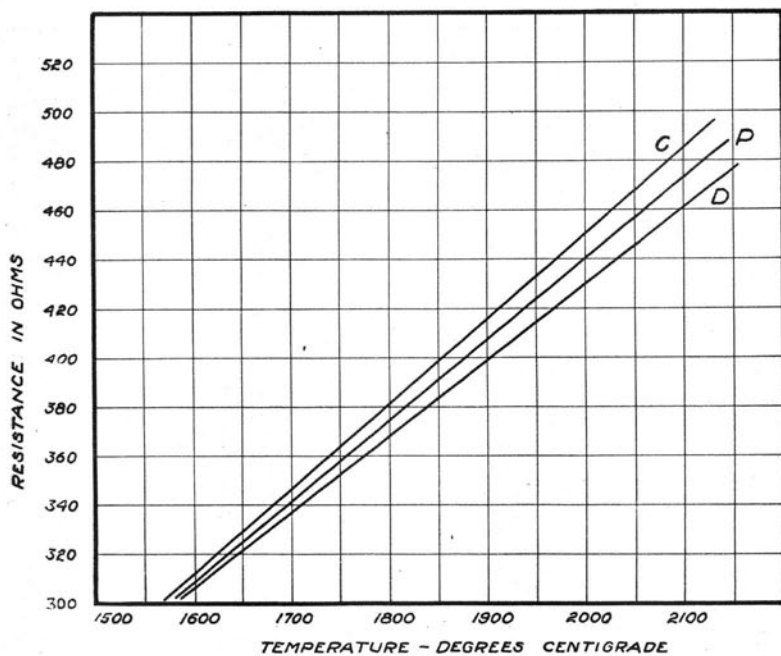


FIG. 5

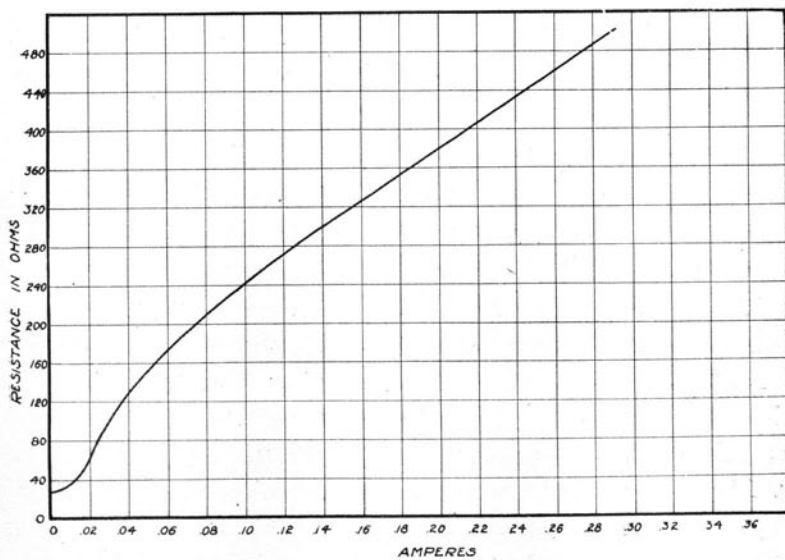


FIG. 6

sistance when the filament is cold, i. e., at zero current, as shown in Fig. 6, gives rise to a heavy rush of current at the first instant which quickly decreases, owing to the rapid increase of resistance as the filament heats up. This current rush, when the lamp is

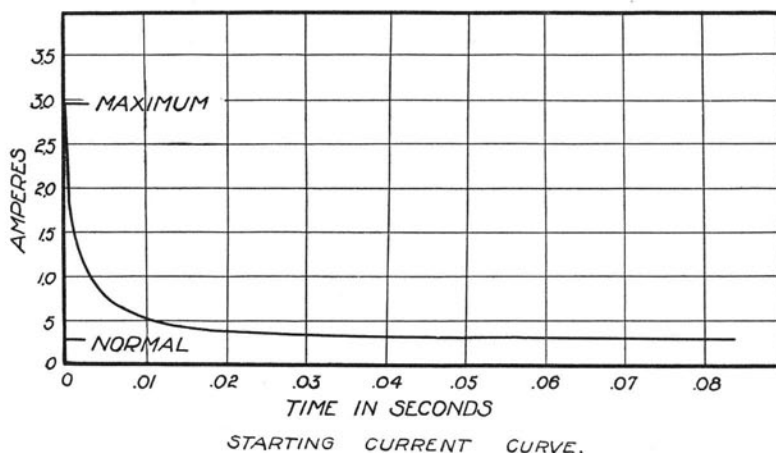


FIG. 7

turned on, causes the familiar flash or sudden rise in candle-power above normal, commonly known as overshooting.

The curves between candle-power and voltage, and between watts per candle and voltage, are shown in Fig. 8. The equation for the former, obtained by the method of least squares is

$$CP = 213.7 \times 10^{-8} \times E^{3.44}$$

Fig. 9 shows curves plotted between watts per candle and temperature,¹ for one lamp of each kind. These curves lie very close together, indicating that throughout the temperature range all three filaments give approximately equal watt per candle efficiencies for the same filament temperatures. Fig. 10 gives curves between temperature and spherical candle power per square inch of total filament area or emissivity. These indicate that the *C* lamp has the highest and the *D* lamp the lowest emissivity at all temperatures. This can be explained by an examination of the fila-

¹ The temperatures given in this bulletin are black body temperatures and are given as relative rather than absolute values.

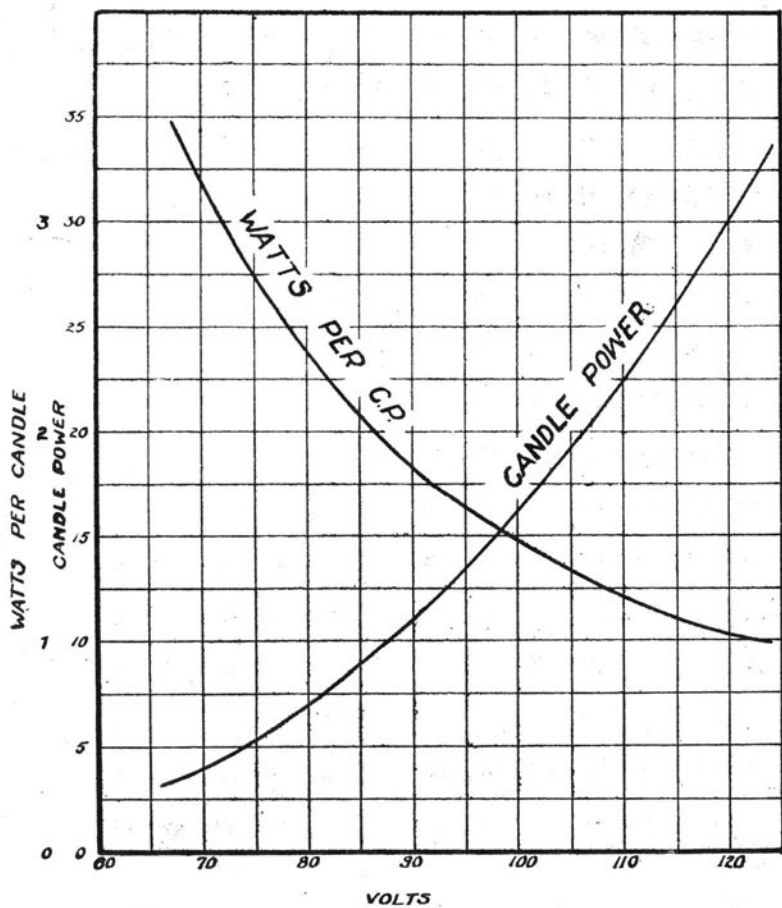
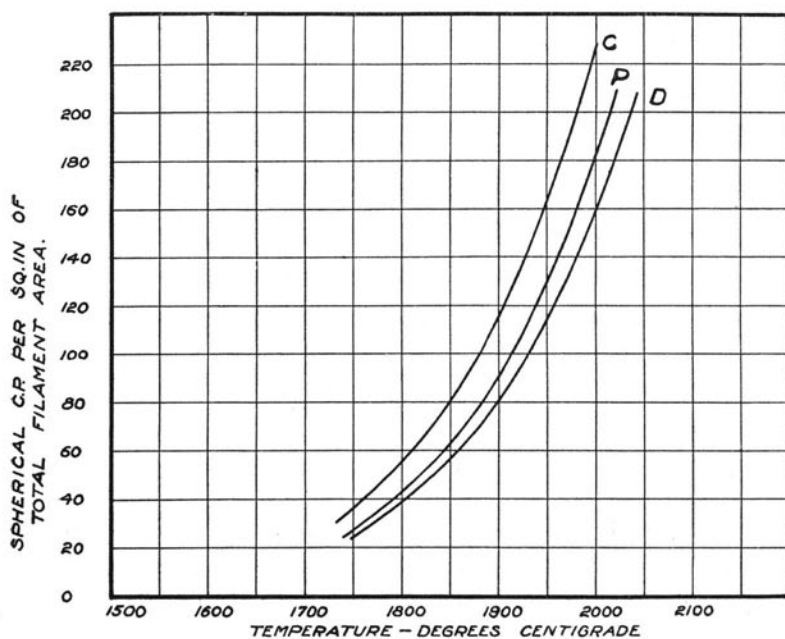
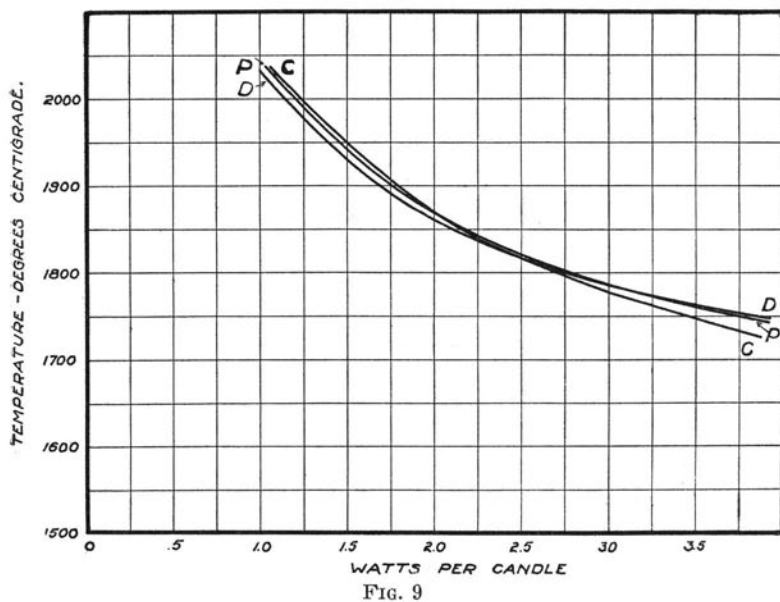
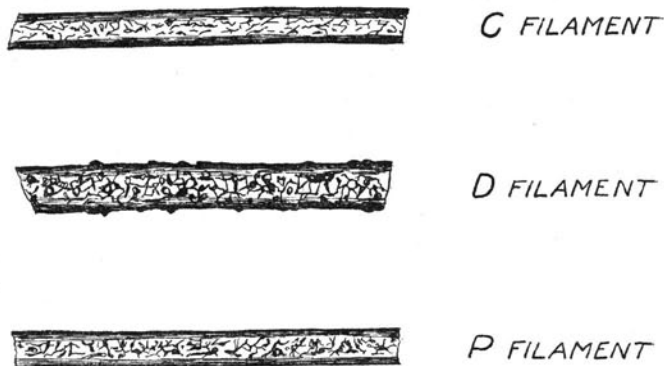


FIG. 8

ments under a microscope. Fig. 11 is a sketch of all three filaments showing their appearance when magnified. The *C* filament is seen to be the smoothest one of the three. It has no pits or protuberances, but has a smooth shiny surface broken only by what look like fine cracks similar to the fine check cracks sometimes seen in the glazes of porcelains. Such a smooth polished surface would naturally have a high emissivity. The *P* filament seems smooth, i. e., is free from knobs and protuberances, though it is covered with small depressions and wrinkles, probably due to the





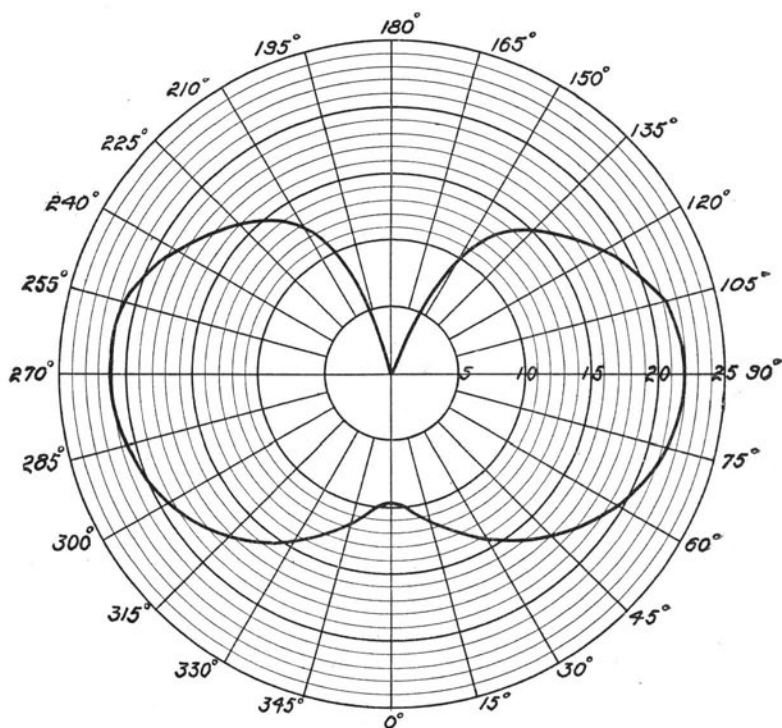
SKETCH OF NEW FILAMENTS WHEN MAGNIFIED.

FIG. 11

removal of the carbon of the binder and the consequent shrinkage. The lines shown on the filament in the sketch represent fine wrinkles rather than cracks on the surface of the filament. These depressions and wrinkles on the surface make its emissivity somewhat less than that of the smoother *C* filament. The *D* filament is the roughest and most uneven of the three. It is covered with many knobs and protuberances, pits and large wrinkles. This rough surface naturally has a lower emissivity than the other two lamps.

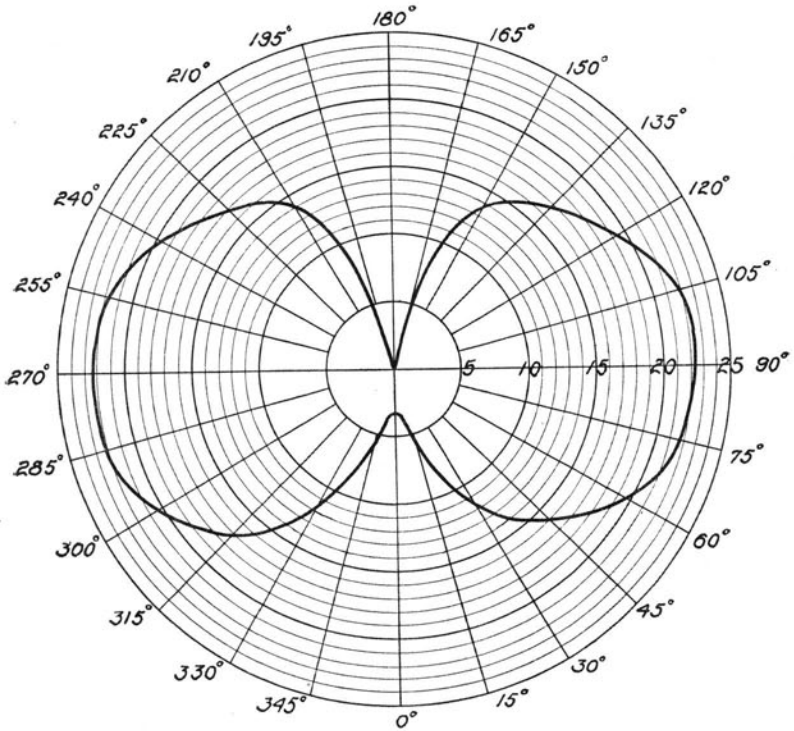
IV. DISTRIBUTION

The horizontal distribution curves for all three lamps are approximately circles, as would be expected from the number and arrangement of the filaments. The vertical distribution curves are shown in Fig. 12, 13 and 14. The *D* lamp has the lowest tip candle power, the *P* lamp next, and the *C* lamp the highest,—nearly 10



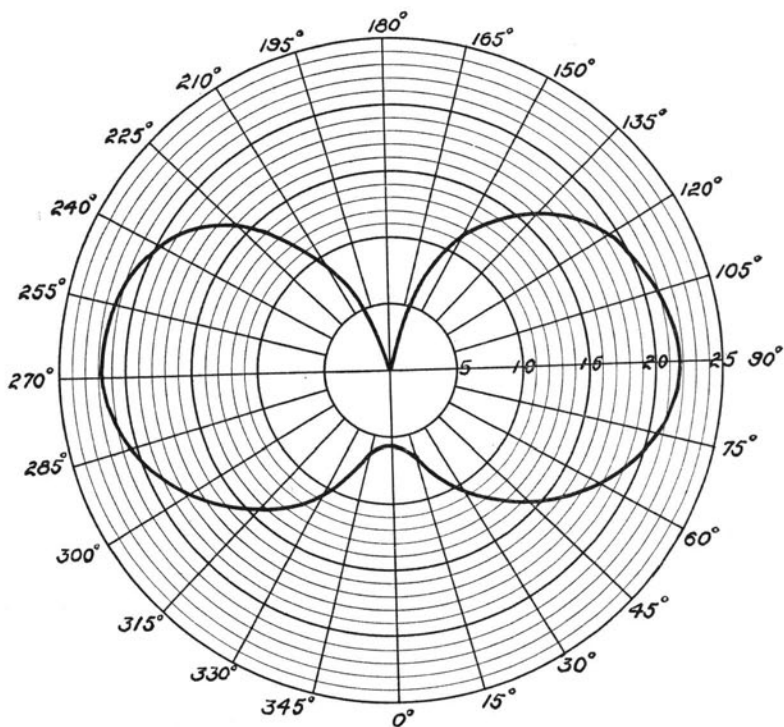
VERTICAL DISTRIBUTION OF $\frac{1}{2}$ C LAMP

FIG. 12



VERTICAL DISTRIBUTION OF D LAMP

FIG. 13



VERTICAL DISTRIBUTION OF P LAMP

FIG. 14

candle-power. The spherical reduction factors for the lamps are shown in the following table.

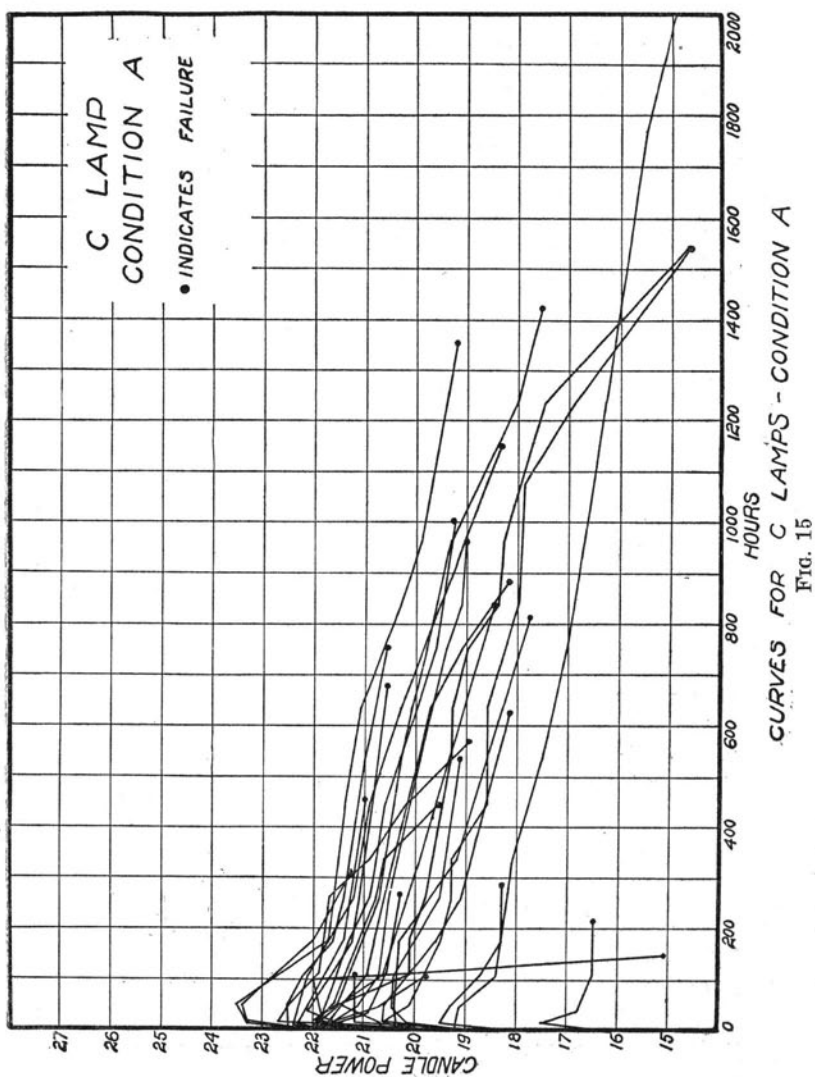
TABLE 2

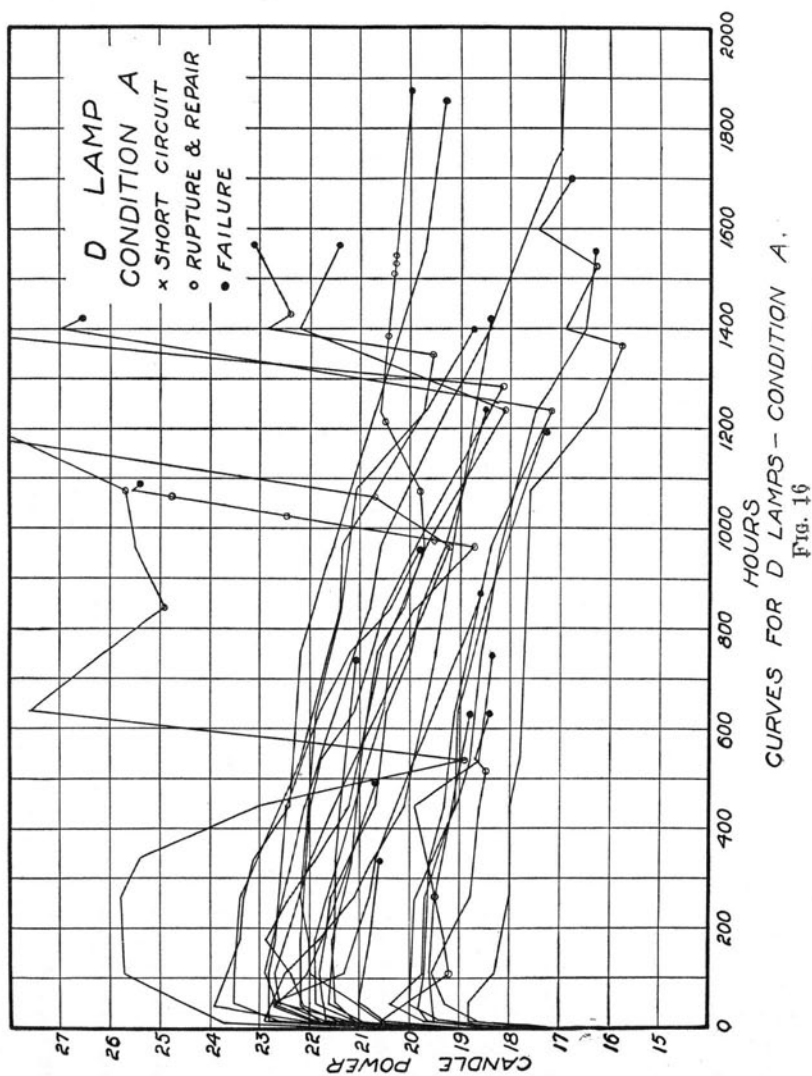
Lamp	Mean Horizontal Candle Power	Mean Spherical Candle Power	Spherical Reduc- tion Factor
<i>C</i>	21.1	17.7	.840
<i>D</i>	22.2	16.2	.730
<i>P</i>	21.9	17.2	.785

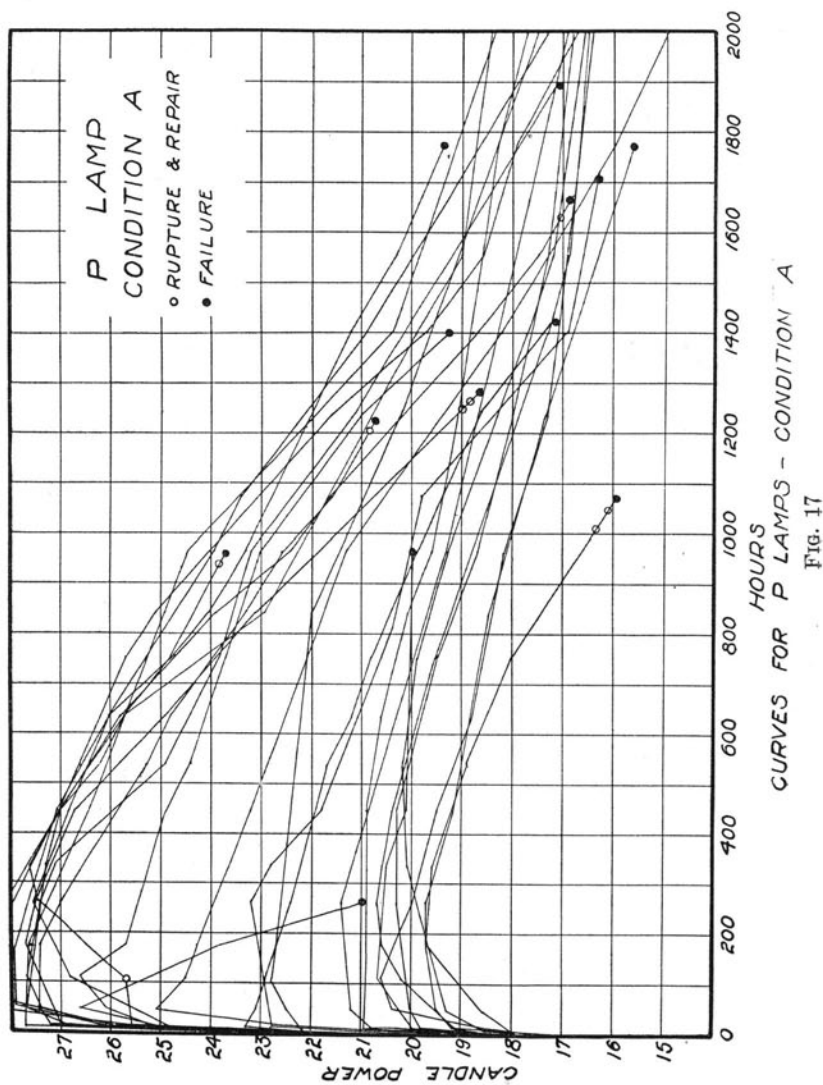
V. LIFE TESTS

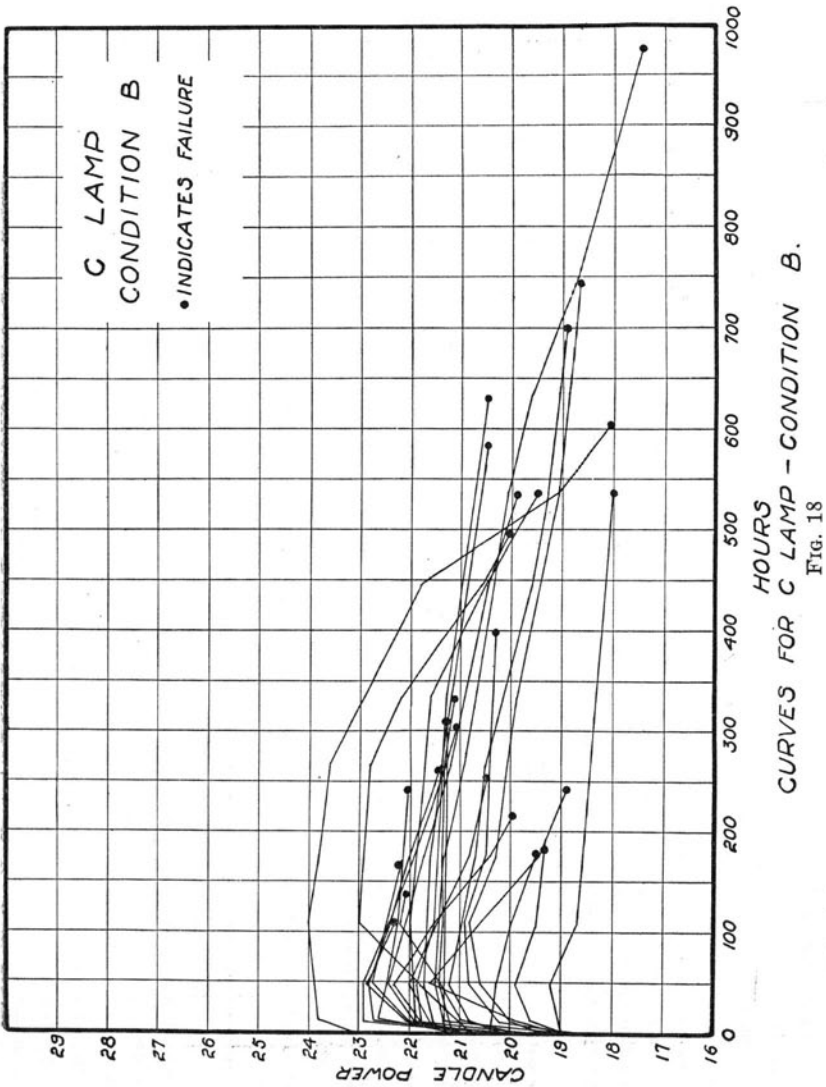
For the life tests, 50 lamps of each kind were selected. Of these, 25 of each kind were burned upon a well-regulated voltage, supplied by a storage battery floating across constant voltage mains. The racks holding the lamps were supported by three coil springs in order to protect them from the vibration of the building. This condition will be designated as A, and represents exceedingly good operating conditions. The remaining 25 lamps of each kind were operated upon 60-cycle alternating current mains having a badly fluctuating voltage. The rack supporting these lamps was rigidly fastened to the floor and received all of the vibration of the building. This vibration was caused by the engines of the University power plant and the machines in the electrical laboratory two floors below. It was great enough to be easily felt by placing the hand on the rack, and the lamps themselves could be seen to vibrate. It was not so severe a vibration as that to which lamps would be subjected in many manufacturing plants, but it was severe enough to represent rather trying operating conditions. This condition will be designated as condition B. Fig. 15 to 20 show the candle-power performance of each lamp on the life tests for both operating conditions.

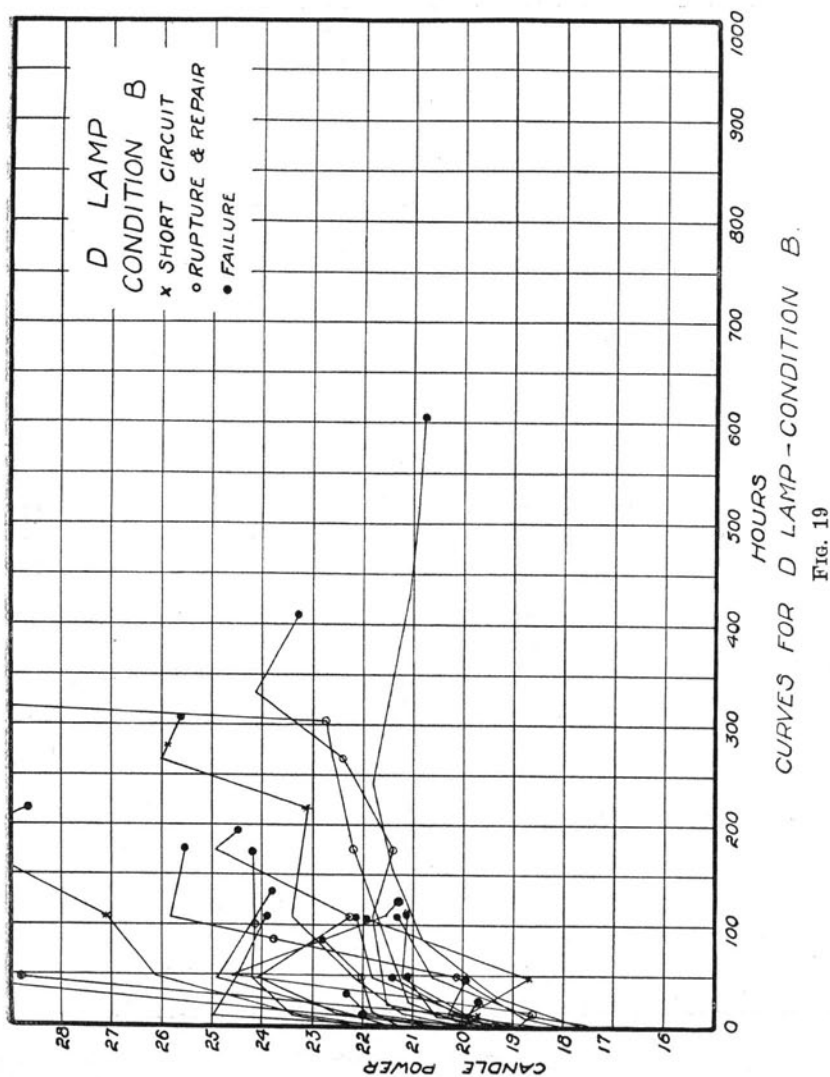
In the life test under condition A, readings were taken up to 2000 hours. At the end of this time there was one *C* lamp, one *D* lamp and thirteen *P* lamps still burning. The method of mounting the filament of the *C* lamp is such that it is seldom that a brok-

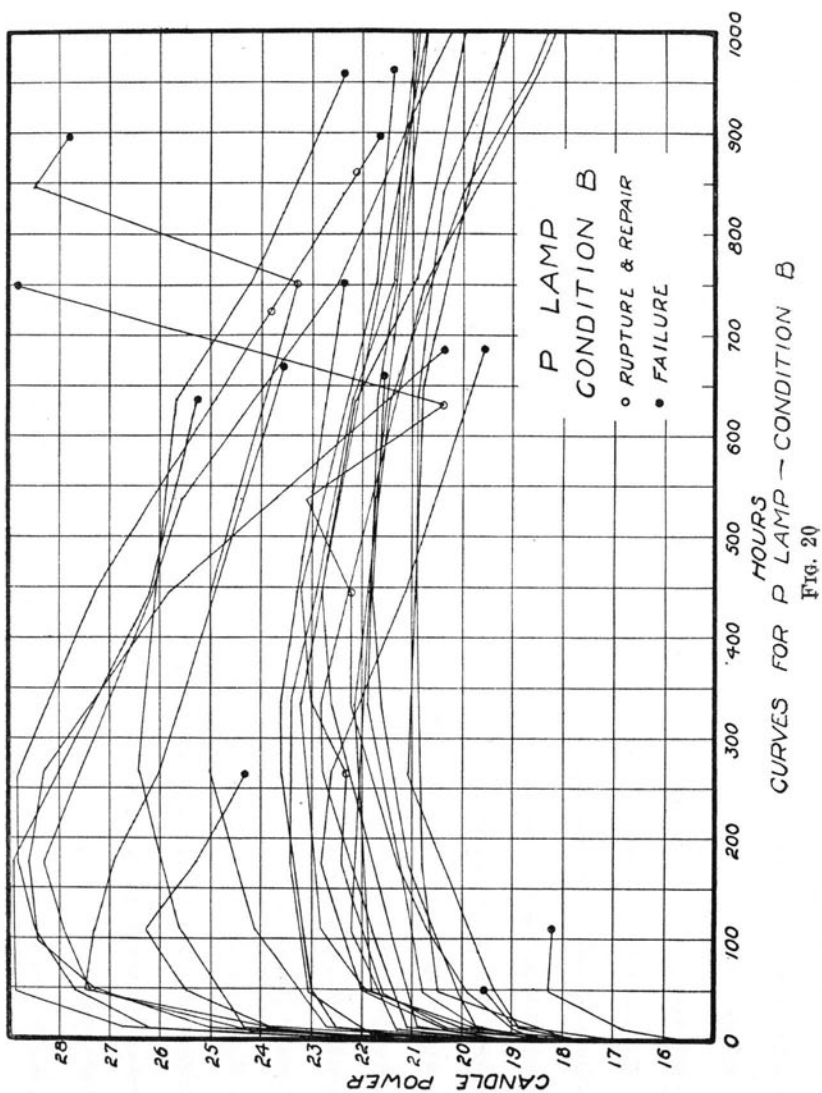












en filament can be repaired. For this reason, the curves for this lamp are very uniform, not showing the sudden increases and decreases that occur in the other lamps. In the *D* lamp the filaments can easily be welded when broken, in fact it is seldom that they can not be repaired after the first rupture. The sudden increases of candle-power that are so often noticeable in the curves for this type of lamp are caused by the welding and consequent decreases in the length of the filament.

In the *C* lamp, failures commenced after about 100 hours of burning and continued steadily for about 1500 hours, when all the lamps but one were gone. Failures in the *D* lamp began at about 300 hours, and at 1900 hours only one was burning. With the *P* lamp, there was one failure at about 300 hours, and then no more until after 900 hours, when they commenced to fail at the rate of about one every hundred hours.

Compared with the results under condition A, those under condition B are rather surprising. The *D* lamp, which made a satisfactory showing under good conditions of operation, did very poorly indeed when operated under adverse conditions. At the end of 600 hours all the lamps were burned out, having an average life of only 153 hours. The *C* and the *P* lamps, as might be expected, gave poorer results than when burning under condition A, but gave a much better average life than the *D* lamps, averaging 434 and 898 hours respectively.

The explanation of the poor life of the *D* lamp under condition B is very simple. These filaments are strung so that they are under tension and the stem upon which they are mounted is supported between two spiral springs. The object of these springs is to absorb the vibrations to which the lamp may be subjected, but the springs are so strong and the stem itself is so light that instead of protecting the filament from the vibrations, they simply take them up and hold them persistently, and of course set the tightly strung filaments to vibrating also. Often some of the filaments of the lamps on test would be seen to vibrate like a violin string with an amplitude that would occasionally become great enough to allow the two sections of a filament to touch and short

circuit themselves. A slight jar would often be sufficient to start these vibrations. It happens also that the tension, mass and length of some filament sections are such that when burned upon alternating current, persistent vibrations will be set up, due either to the presence of a stray¹ magnetic field or to the magnetic repulsion and attraction action of adjacent filament sections. Upon 50-cycle current, which is common in Germany where these lamps are manufactured, some filament sections would vibrate strongly when in a magnetic field, though there were fewer that would do so than there were on 60 cycles.

On account of being mounted without tension, the filaments of neither the *P* nor the *C* lamps would vibrate upon either the 60 or 50 frequency current, unless placed in a strong magnetic field, for instance, between the poles of a horse shoe magnet. When in a strong field, the filaments of both lamps formed a node in the middle and vibrated in two sections. After a long period of burning, the *P* lamp filaments would sometimes be sufficiently contracted to put some of the filament sections under tension, and then the same persistent vibrations would be noticed in them as in the *D* lamp.

VI. CANDLE-POWER MAINTENANCE AND CHANGE IN EFFICIENCY

The curves in Fig. 21 to 24 show the changes in candle-power and efficiency for the three lamps, the curves representing the mean performance of all the lamps tested. All three lamps show the increase in candle-power during the first few hours of burning, and the subsequent falling off in candle-power that is usual with incandescent lamps. The *P* lamp, however, shows the greatest change. It also maintains the highest average candle-power throughout the test, the *D* lamp being next and the *C* lamp the lowest. After 2000 hours' burning, the average candle-power of

¹ The only magnetic field that was near enough so that there was any possibility of its affecting the lamps was due to a direct current circuit carrying 7 amperes and it was at a distance of about 8 feet from the test rack so that its effect must have been very small.

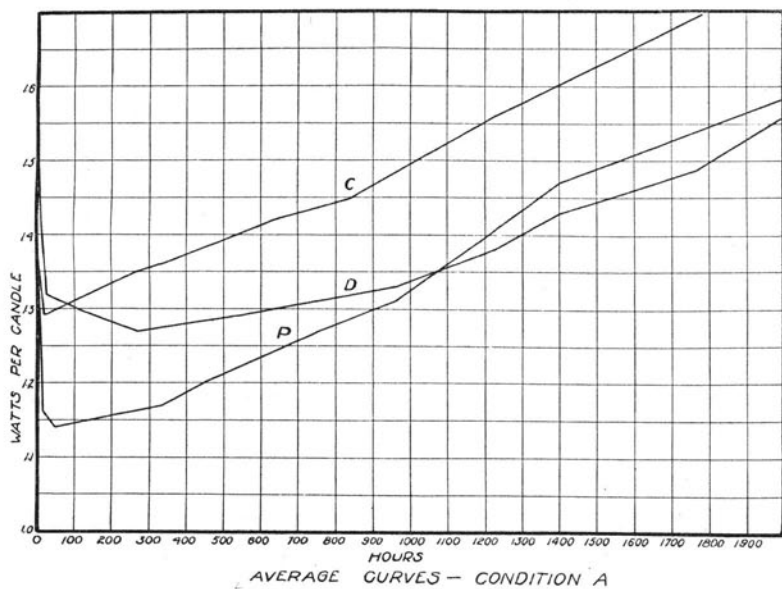


Fig. 21

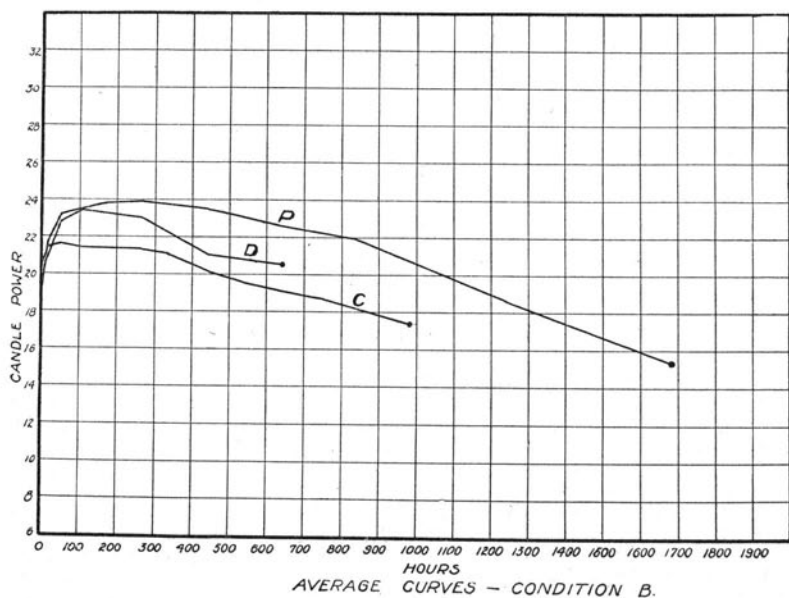


Fig. 22

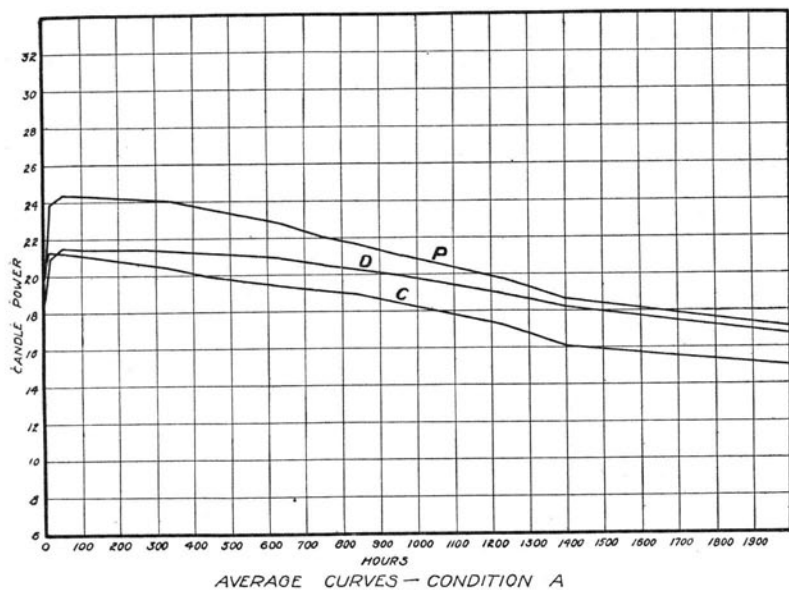


FIG. 23

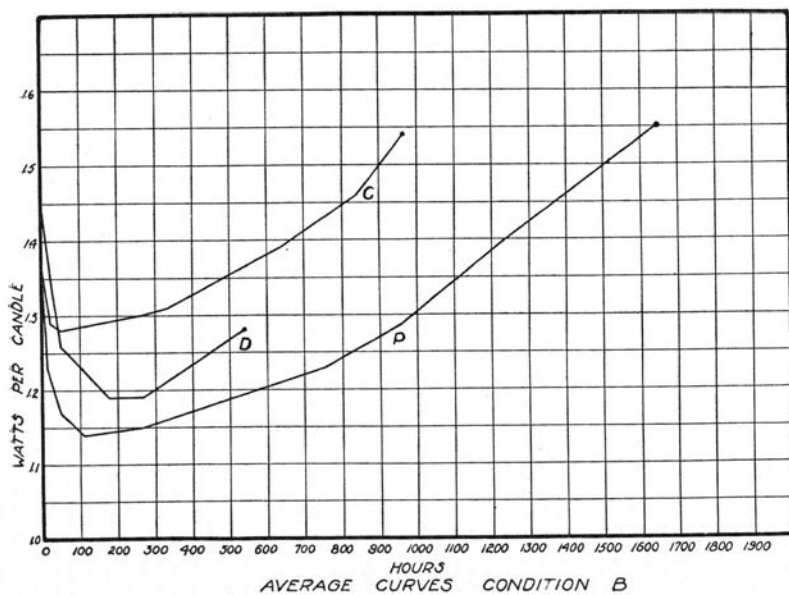


FIG. 24

the *P* lamps decreased to 88 per cent, the *D* lamps to 89 per cent and the *C* lamps to 77 per cent of the initial value.

The curves of average efficiency show the *C* lamp to have the highest watt per candle consumption throughout the tests. Up to about 1100 hours, the *D* lamp gives a poorer efficiency than the *P* lamp, but at this point the curves cross and the *D* lamp gives the better efficiency from that time on. This change in the relative efficiency of the two lamps is due to the greater blackening of the bulb of the *P* lamp.

Bulb Discoloration.—For the purpose of securing a standard by which the discoloration of the different lamps could be compared, a series of 10 carbon lamps was obtained from the Electrical Testing Laboratories of New York. These lamps had been burned for different periods and consequently carbon deposits of different densities were formed on the bulbs; they ranged in intensity from 95 per cent of the original candle-power down to 66.9 per cent. They were numbered from 1/2 to 5 as shown below.

TABLE 3

Lamp No.....	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5
Per cent C. P.:	95	91.3	86.9	83	78.6	75.3	73	70.5	68.7	66.9

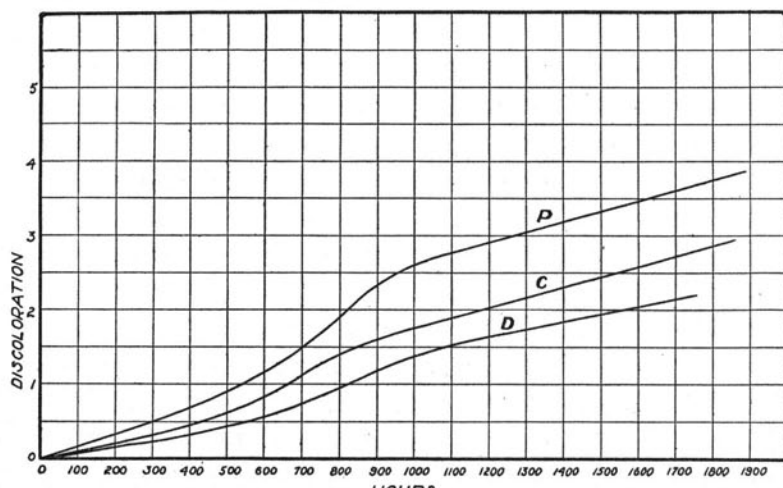


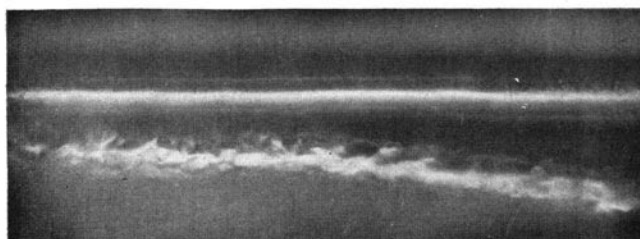
FIG. 25

At intervals throughout the life test, the color of each tungsten lamp was compared with that of the series of carbon lamps, and the number with which it matched in color was noted. In this way the rapidity with which the tungsten lamps blackened could be determined. The lamps did not blacken uniformly over the surface, hence the darkest portion was always chosen for comparison. Fig. 25 shows the results obtained. It is plotted between hours of burning and discoloration and represents the average results of 25 lamps of each kind. The *P* lamp shows the most pronounced discoloration while the *D* lamp shows the lowest. The *P* lamps were decidedly non-uniform in the rapidity with which they blackened. Some of them would be discolored scarcely any after 1000 or 1500 hours' burning, while the others would be as black as the No. 5 carbon lamp. The *C* and *D* lamps seemed to blacken uniformly, so that at any time all of the lamps of either of these types would be discolored approximately the same amount.

In Fig. 26 are microphotographs showing the condition of the filaments after a long period of burning. In each case a new filament is shown for comparison. As might be expected, all three filaments become much roughened and pitted after a period of burning, and decrease somewhat in size, the *D* filament to a considerable extent. Filaments burned upon alternating current are the same in appearance as those burned upon direct current for the same length of time and do not show the segmentation that takes place in tantalum filaments.

A summary of the performance of the lamps on the life and efficiency tests is shown in Table 4. The curves in Fig. 27 and 28 are plotted between "Total cost in cents per candle-power-hour for lamps and energy" as ordinates and "Cost of energy per kilowatt-hour" as abscissas. The curves for condition A are drawn from calculations based upon a 2000-hour test and those for condition B from calculations based upon a 1000-hour test.

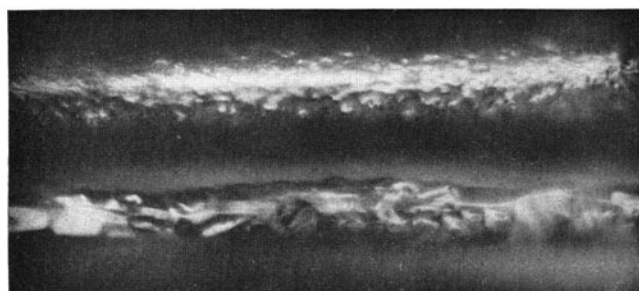
On account of the lower cost of lamp and the fewer burnouts, the *P* lamp gives a considerably lower total cost of operation than the other two. The cost of operating the *D* lamp under condition



New

After burning
1000 hours

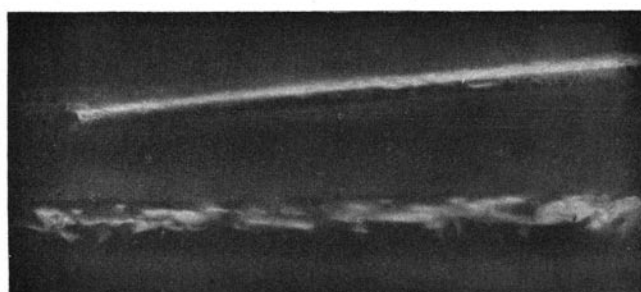
C Filament



New

After burning
1000 hours

D Filament

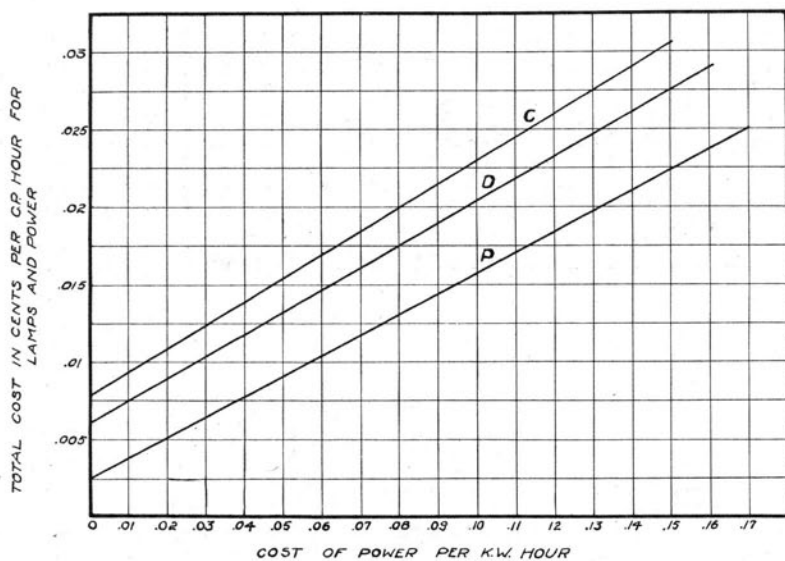


New

After burning
1000 hours

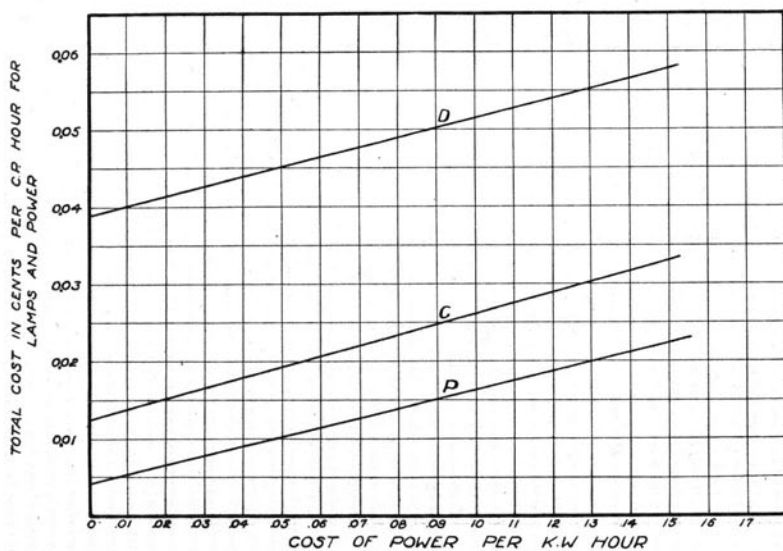
P Filament

FIG. 26



Condition A

FIG. 27



Condition B

FIG. 28

TABLE 4
SUMMARY OF LIFE AND EFFICIENCY TESTS

Lamp Operating Condition	C		D		P	
	A	B	A	B	A	B
Av. Mean Horizontal C. P.						
a. New	19.9	20.6	18.6	19.9	19.9	19.3
b. 1000 hours	18.2		19.7		20.8	20.6
c. 2000 hours	15.0		16.7		191	
Spherical Reduction Factor	.840		.730		.785	
Av. Watts per Lamp	27.5	27.4	28.0	28.0	27.7	27.0
Av. Initial Watts per C. P.	1.36	1.36	1.48	1.44	1.32	1.32
Av. Life in Hours	762	434	1167	153		898
Av. C. P. through Life	18.2	20.2	19.5	22.5	20.9	22.5
Cost Lamps to run 1000 hrs.		\$62.64		\$220.05		\$23.80
" " " 2000 "	\$70.28		\$58.05		\$25.50	
C. P. Hours per Lamp	36,400	20,200	39,000	22,500	41,800	22,500
Total C. P. Hours	910,000	505,000	975,000	562,000	1,045,000	562,000
Kilowatt Hours	1,375	685	1,400	700	1,385	675
Cost of Lamps	\$1.08		\$1.35		\$.85	

B is excessively high on account of the exceedingly short average life of the lamps under this condition; in fact, for power costs below 12 or 13 cents per kilowatt-hour, they are more expensive to operate than ordinary carbon filament lamps.¹

VII. CONCLUSIONS

Comparisons of the durability of filaments made by the colloid, deposition and paste processes are very difficult to make owing to the fact that the three types were all mounted differently. Undoubtedly the manner of mounting a filament has a great effect upon its life, and whether the superior life of one type of lamp is due to the fact that it has a better scheme of mounting or to the fact that the process of manufacture is better, can hardly be decided definitely from these tests. Tests of filaments made by the three processes and mounted in exactly the same way would be necessary to decide this question absolutely. From the tests just

¹ In Engineering Experiment Station Bulletin No. 19 are given the results of tests upon carbon, metallized carbon and tantalum lamps which may be compared with the results given in this bulletin for tungsten lamps. It should be said, however, that the metallized carbon and tantalum lamps used for the tests described in Bulletin No. 19 were manufactured three or more years ago and that lamps of these kinds now manufactured and put upon the market show a considerable improvement over the ones tested.

described, however, the colloid process seems to give a filament that is less durable than the other two. It is true that when tested under condition B, it gave a longer life than did the *D* lamp, but this was because its construction enabled it to withstand vibration better rather than because of the superior quality of the filament. Under condition A where vibration was eliminated and where the scheme of mounting had less effect upon the life, the *D* lamp gave a considerably longer life. The *P* lamp gave a much better life under both conditions of operation than the *C* and *D* lamps. This must be due at least in part to the fact that the filament has better lasting qualities than those made by the other processes. Under condition A, this lamp shows the same superior life as it did under condition B where differences in mounting produce great differences in average life.

Of the three schemes for mounting the filaments, that of the *C* lamp undoubtedly holds the filament more nearly in the desired place for all positions of burning than the other two. While holding it in the proper position, it at the same time holds it loosely enough so that all necessary contraction can take place without putting it under a tension that is likely to cause it to respond readily to vibrations. The principal defects of this scheme of mounting are that it lacks simplicity and that there are a large number of supporting spires that carry off by heat conduction energy that should be radiated in the form of light. For burning in a vertical pendant position or nearly so, the mounting of the filament in the *P* lamp is very good. The filament is held loosely so that contraction can take place without putting it under sufficient tension for vibration to have the serious effect upon it that it does upon the *D* filament. When burning horizontally it sags considerably, often enough to allow it to touch the glass stem supporting it. This at least gives the lamp a poor appearance even if it caused no other bad effects. The mounting of the *D* filament permits almost no distortion of the filament to take place when burning horizontally, but it has the serious fault of holding the filament in tension so that it responds readily to vibrations. The spring suspension of the supporting stem tends

to make worse the very thing that it is intended to prevent. No doubt there would be less trouble from vibration with this style of filament mounting if the stem were rigid. That there would still be bad effects from vibration even if the stem were rigid is proved by the *P* lamp. When a filament section in this lamp, which has a rigid stem, contracted sufficiently to put it under tension, as sometimes happened, it would respond to vibrations when burning under condition B in the same way that the *D* filament did, and then quickly fail. A considerable number of the newer tungsten lamps coming on the market have their filaments mounted under a slight tension, just as in the *D* lamp, but where they are to be subject to vibration, it is doubtful if they will give as good results as more loosely strung filaments would.

These tests show that the performance of tungsten lamps may vary to a surprising degree depending upon the kind of lamps used and upon the conditions under which they are burned. Some lamps will give as high operating cost as the old carbon lamps while burning under certain conditions, whereas other lamps will give good results under those same conditions. Under the best conditions, however, the tungsten lamps now on the market give excellent results. Their efficiency is maintained in a remarkable way and the life is very long, often several times what they are advertised to give.

Breakage in shipment and handling have been reduced to a small fraction of what was common in the early lamps. Only three of the three hundred lamps which were purchased for these tests were received with broken filaments, and although the lamps on some of the tests which have been described were handled dozens of times, almost no trouble was experienced so far as the breakage of filaments was concerned.

The other defect of the early lamps, that of early blackening of the bulbs, seems to have been overcome. Not one of the lamps on the tests showed any early discoloration at all, in fact, not until after about 600 hours of burning did any of the bulbs show an appreciable amount of blackening.

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